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Soil Organic Matters for Soil Health

Dr. Kate Congreves

Department of Plant Sciences, University of Saskatchewan

kate.congreves@usask.ca
Twitter@KateCongreves

Res rustica
"Agriculture"
by L. Columella

wikipedia.com

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What *is* soil health?

- Nebulous (Lancaster et al. 2000)
- Metaphorical (Callicot 1992, Lovelock 2000)
- Context dependent (Bennett et al. 2010)
- Evocative but ambiguous (Janzen and Gregorich 2015)
- Inherent yet dynamic

Photo Credits: K. Congreves

What *is* soil health?

"Vitality of a soil in sustaining socio-ecological functions of its enfolding land"

Janzen and Gregorich (2015)

"Overall picture of soil functionality"

Arias et al. (2005)

"Capacity to function as a vital system"

Doran and Zeiss (2000)

"Capacity to function"

Karlen et al. (1997)

"Functionality of soil"

Cardoso et al. (2013)

"Capacity of a soil to function, within ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health"

Doran and Parkin (1994)

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Functioning at optimal capacity?

Suitable for use?



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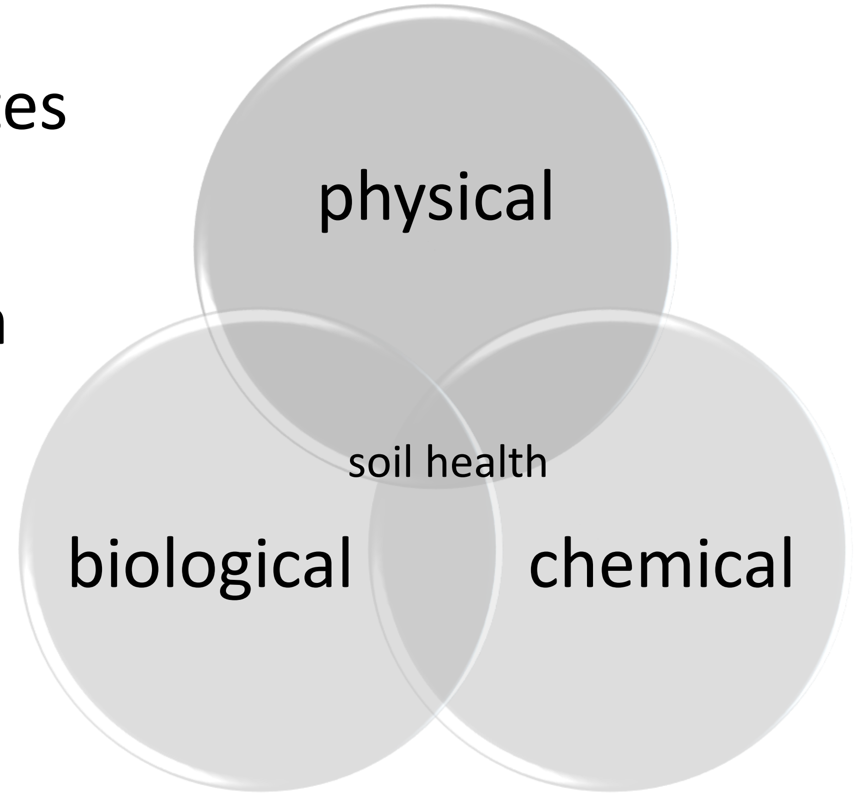
Challenges & Opportunities

- How do we foster, maintain, or build the health of our soils?
- Measuring soil health?
- How to study soil health?
  - Temporal and spatial scales?
  - Numerous soil functions?
  - Trade-offs in soil ecosystem service functioning?

Measuring soil health?

- Challenge#1: must integrate numerous physical, biological, and chemical attributes

- Challenge#2: requires long-term research



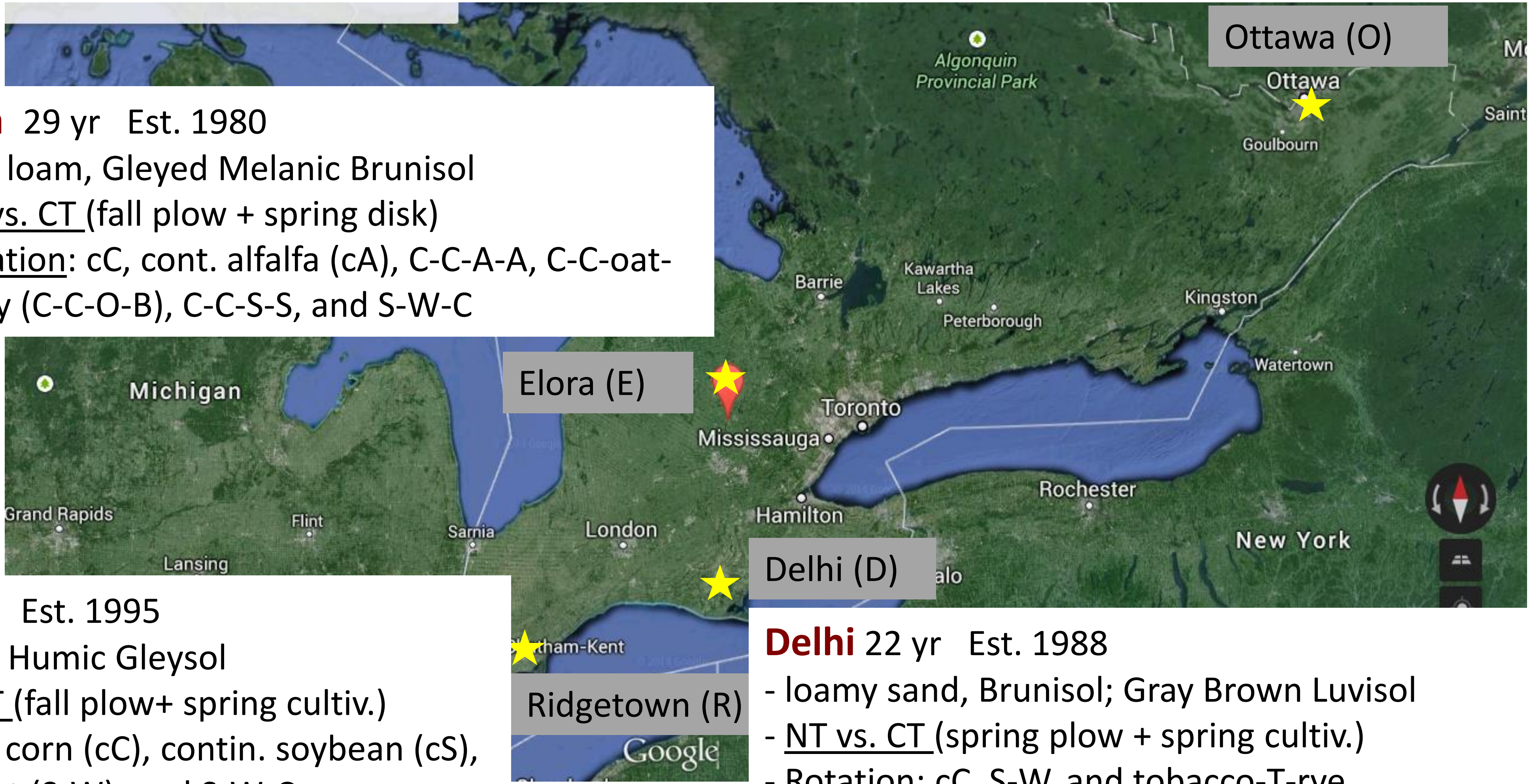
Congreves, K.A., Hayes A., Verhallen A. & Van Eerd, L.L. (2015). Long-term impact of tillage and crop rotation on soil health at four temperate agroecosystems. *Soil and Tillage Research*. 152: 17-28.

Congreves et al. 2014 Can. J. Soil Sci.

Long-term trials

Ottawa 18 yr Est. 1992
- sandy loam, Melanic Brunisol
- NT vs. CT (fall plow + spring disk)
- Rotation: cC, cS, cont. winter wheat (cW), and S-W-C

Elora 29 yr Est. 1980
- silty loam, Gleyed Melanic Brunisol
- NT vs. CT (fall plow + spring disk)
- Rotation: cC, cont. alfalfa (cA), C-C-A-A, C-C-oat-barley (C-C-O-B), C-C-S-S, and S-W-C



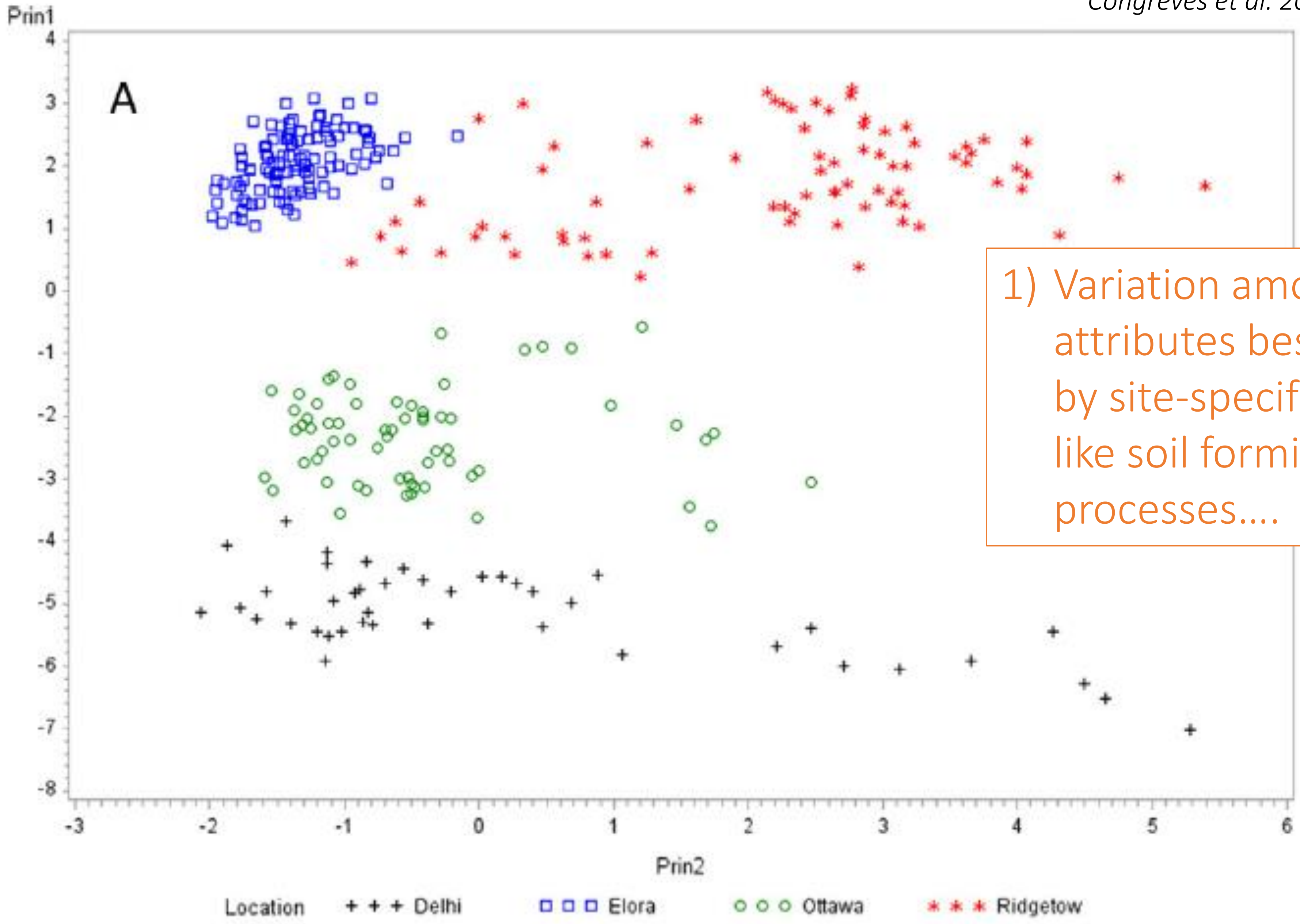
Ridgetown 14 yr Est. 1995
- clay loam, Orthic Humic Gleysol
- No till (NT) vs. CT (fall plow+ spring cultiv.)
- Rotation: contin. corn (cC), contin. soybean (cS), S-C, S-winter wheat (S-W), and S-W-C

Delhi 22 yr Est. 1988
- loamy sand, Brunisol; Gray Brown Luvisol
- NT vs. CT (spring plow + spring cultiv.)
- Rotation: cC, S-W, and tobacco-T-rye

- Cornell Soil Health Assessment, methods according to Gugino et al. (2007)
- Samples collected in June 2009 (Ridgetown, Elora); May 2010 (Delhi, Ottawa)
- 0-15 cm depth of 30 soil cores (1.8 cm dia.) each subplot
- 15 soil chemical, physical, and biological parameters (Certified ON laboratory)

Aggregate stability (%)
Organic matter (%)
Active C (mg kg^{-1})
PMN (mg kg^{-1})
Root health
pH
P (mg kg^{-1})
K (mg kg^{-1})
Ca (mg kg^{-1})
Mg (mg kg^{-1})
Zn (mg kg^{-1})
Zn index
Mn (mg kg^{-1})
Mn index
CEC (M_{eq} 100 g^{-1})

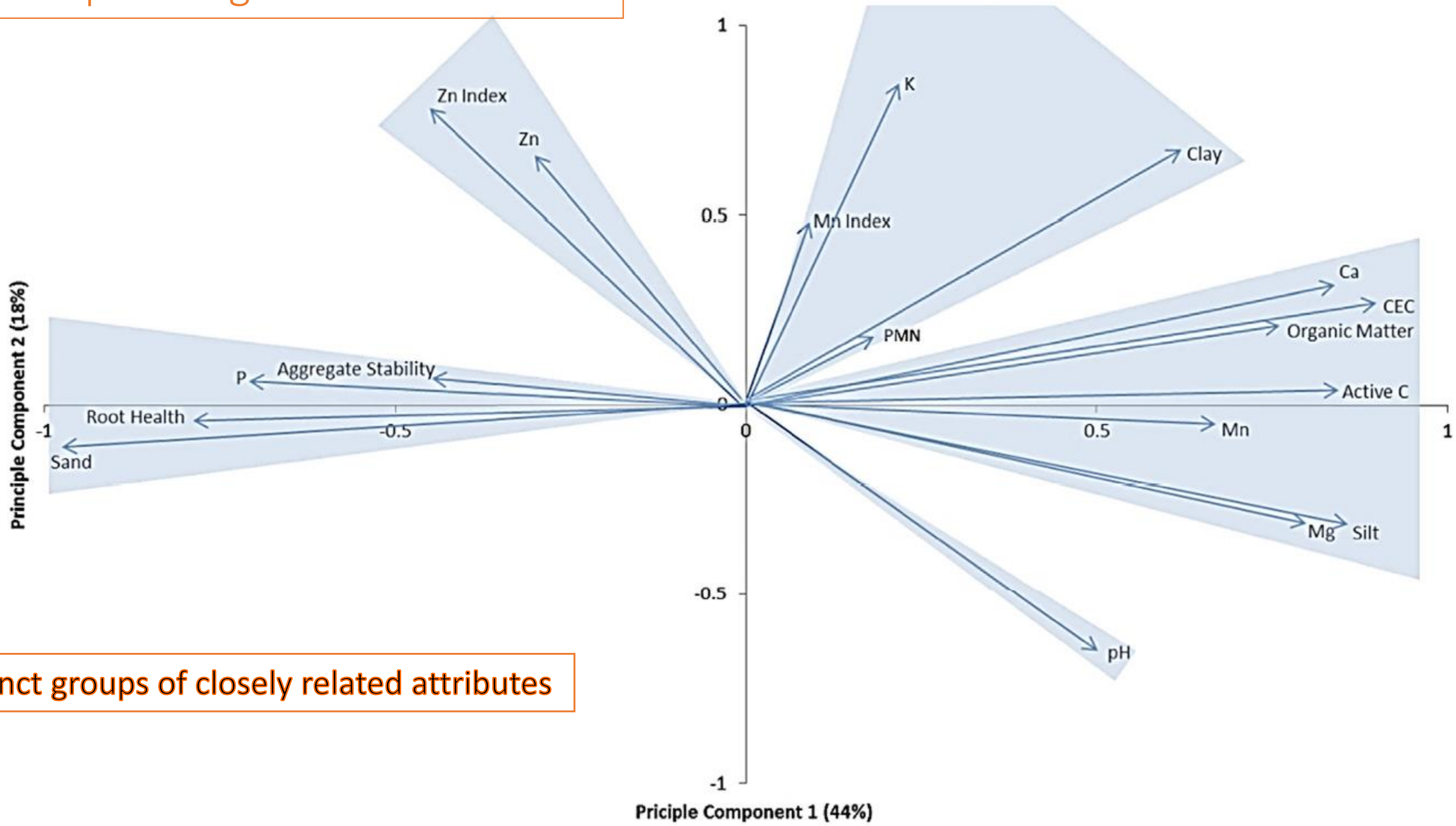
Congreves et al. 2015 Soil & Till Research



1) Variation among all soil attributes best explained by site-specific factors, like soil forming processes….

Congreves et al. 2015 Soil & Till Research

Relationship among soil attributes?



5 distinct groups of closely related attributes

Long-term (14 to 29 years) agricultural production under no-tillage, conventional tillage, and various crop rotations (grains, cereals, legumes, forages)

Congreves et al. 2015 Soil & Till Research

Tillage systems

2 main observations:

1) No-till resulted in higher soil health scores than conv. till
2) Trends similar b/w new weighted scoring vs CSHA, but weighted scores more sensitive which may help growers

Effect of tillage system on soil health scores in 0-15 cm depth from four long-term trials in Ontario

	CSHA score		Weighted 'Ontario' CSHA score	
	Conv. tillage	No-till	Conv. tillage	No-till
Ridgetown	64	68 *	37	64 *
Delhi	57	64 *	33	61 *
Elora	69	73 *	34	59 *
Ottawa	66	66	44	54
Overall	64	68	36	61

Congreves et al. 2015 Soil & Till Research

Crop rotations

Main observation:

1) Crop rotations which included winter wheat, alfalfa, and undersown red clover tended to have highest soil health scores

	CSHA score			
	Ridgetown	Delhi	Elora	Ottawa
cont. Alf			79 a	
cont. Corn	64 b	60	70 bcd	66
cont. Soy	64 ab			62
cont. W				68
A-A-C-C			74 ab	
S-W	70 a	64		
C-S-W or C-C-S-W	66 ab		73 abc	66
C-S-W/rc			72 bc	
C-C-O-B			67 cd	
C-C-O/rc-B/rc			72 bc	
S-C or S-S-C-C	66 b		65 d	
T-T-R		61		

Congreves et al. 2015 Soil & Till Research

Crop rotations

Main observations:

2) Trends similar b/w new weighted scoring vs CSHA, but weighted scores more sensitive which may help growers

	Weighted ‘Ontario’ CSHA score			
	Ridgetown	Delhi	Elora	Ottawa
cont. Alf			93 a	
cont. Corn	48 ab	44	32 bcd	34
cont. Soy	37 b			41
cont. Wheat				70
A-A-C-C			65 ab	
S-W	72 a	51		
C-S-W or C-C-S-W	52 ab		54 bc	49
C-S-W/rc			49 bc	
C-C-O-B			35 cd	
C-C-O/rc-B/rc			59 bc	
S-C or S-S-C-C	33 b		20 d	
T-T-R		49		

General Findings

CSHA score higher soil health with NT vs CT

- At all sites except Ottawa
- Growers encouraged to adopt no-till production

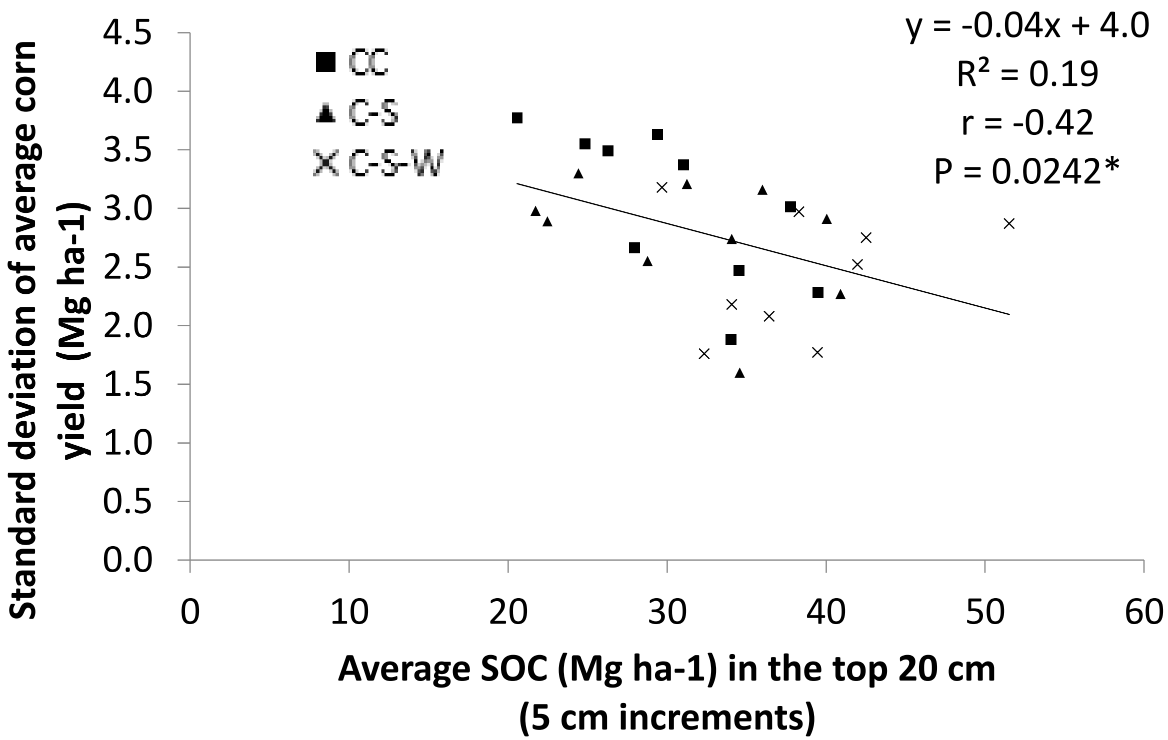
CSHA score tended to be higher with winter wheat, alfalfa, and undersown red clover in the rotation:

- Growers encouraged to include these crops in their rotation
- Less differences with crop rotation than tillage

CSHA scoring system useful, but the weighted ‘Ontario’ CSHA score may help growers to more clearly see differences in soil health under different management practices

Follow-up at Ridgetown

1) Corn yield was less variable as soil organic content increased…esp. with winter wheat in rotation



Congreves, K.A., D.C. Hooker, Hayes A., Verhallen A. & Van Eerd, L.L. (2017). Interaction of nitrogen fertilizer application, crop rotation, and tillage system on long-term soil carbon and nitrogen dynamics. *Plant and Soil*. 410: 113-127.

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Measuring soil health?

- Cornell Soil Health Test
- Solvita
- Haney Soil Health Test
- Minimum dataset

- *Again, measuring and interpreting soil health is challenging…*

- ***Stay tuned – more to come…we'll be working on developing a soil health testing protocol for Saskatchewan producers (ADF partnership with WGRF, SaskCanola, & SWDC 2018-2021).***

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Soil organic matter – matters for soil health

- Integral to all soil health indictors or soil health tests
- Long periods before a change is measureable

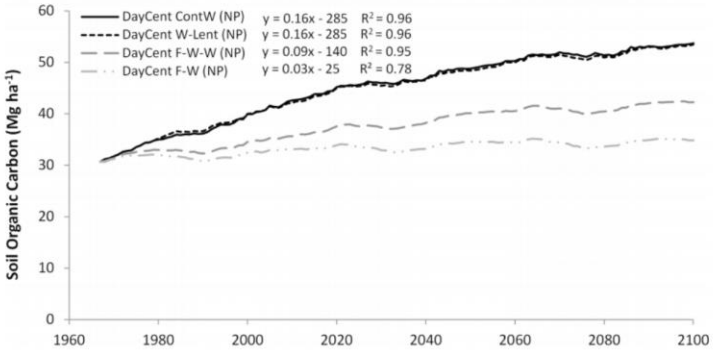
Soil aggregation → Soil structure → *Erosion resistance*

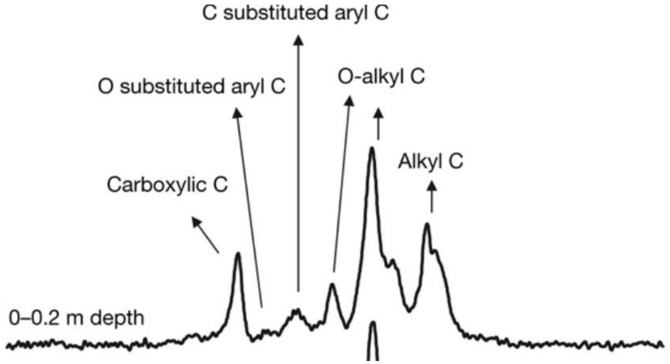
Water holding capacity ↓ Aeration ↓ Bulk density

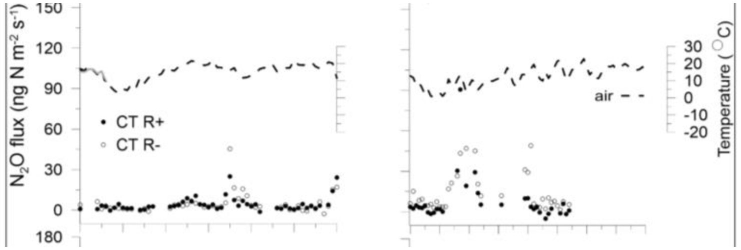
Soil nutrient reservoir → Soil carbon storage → *Soil functioning*

Soil health, organic matter, and functioning

Soil nutrient reservoir → Soil carbon storage → Soil nitrous oxide emissions







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Soil organic matter – a nutrient reservoir

~ 2-3% is mineralized annually

Stabilized matter:

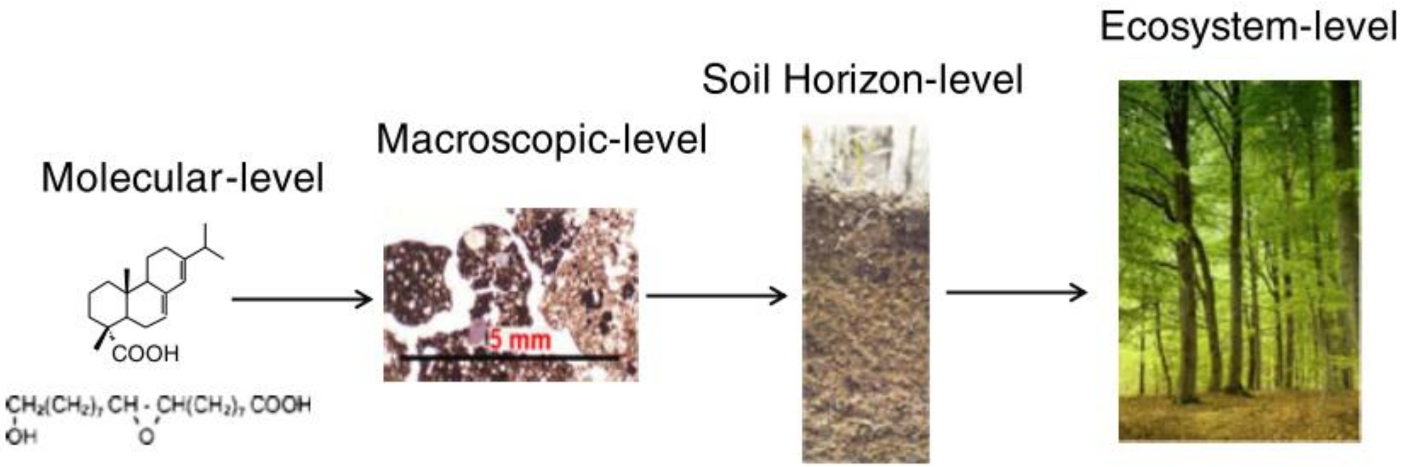
- humus, 1000-3000 yrs old
- 58% carbon
- C:N = 10, C:P = 50, C:S = 50

Decomposing matter + fresh residues:

- Recognizable biomass (plant/animals)
- chemical structures
- Root exudates & substances produced by soil organisms

Live biomass:

- roots
- cells and tissues of soil organisms



Simpson and Simpson 2012

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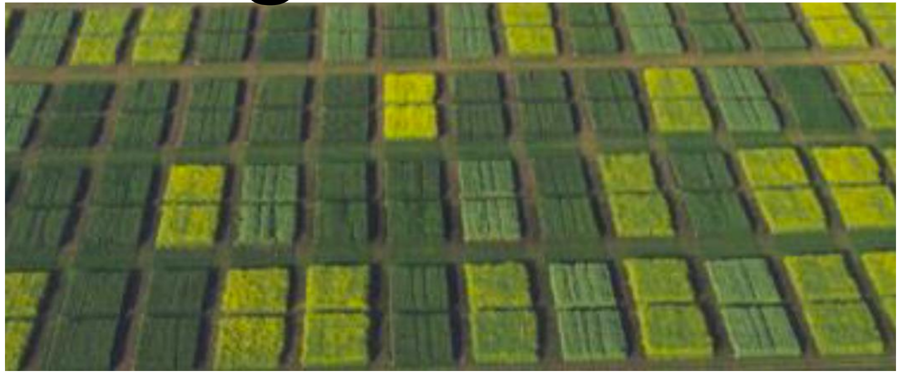
Soil carbon – long-term trials are indispensible



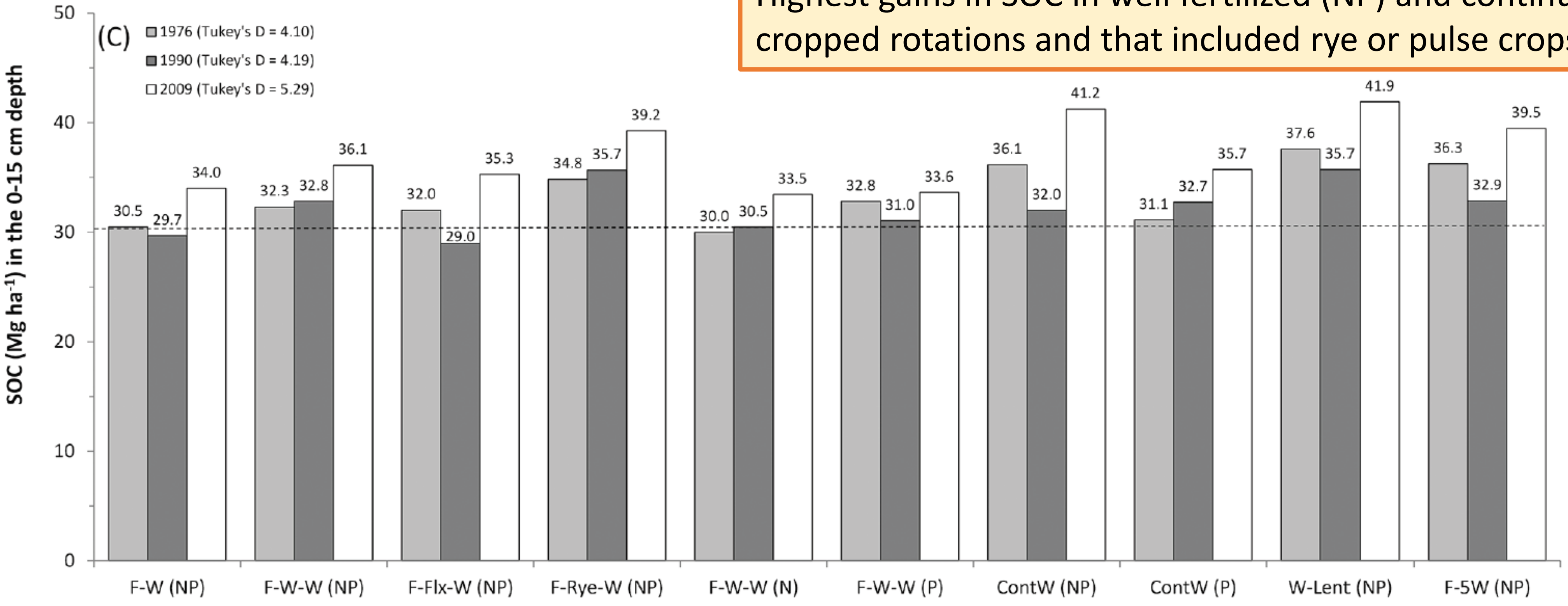
Volume 5 (2012) - Long-Term Crop Rotations in the Canadian Prairies

https://prairiesoilsandcrops.ca

Swift Current Old Rotation Trial

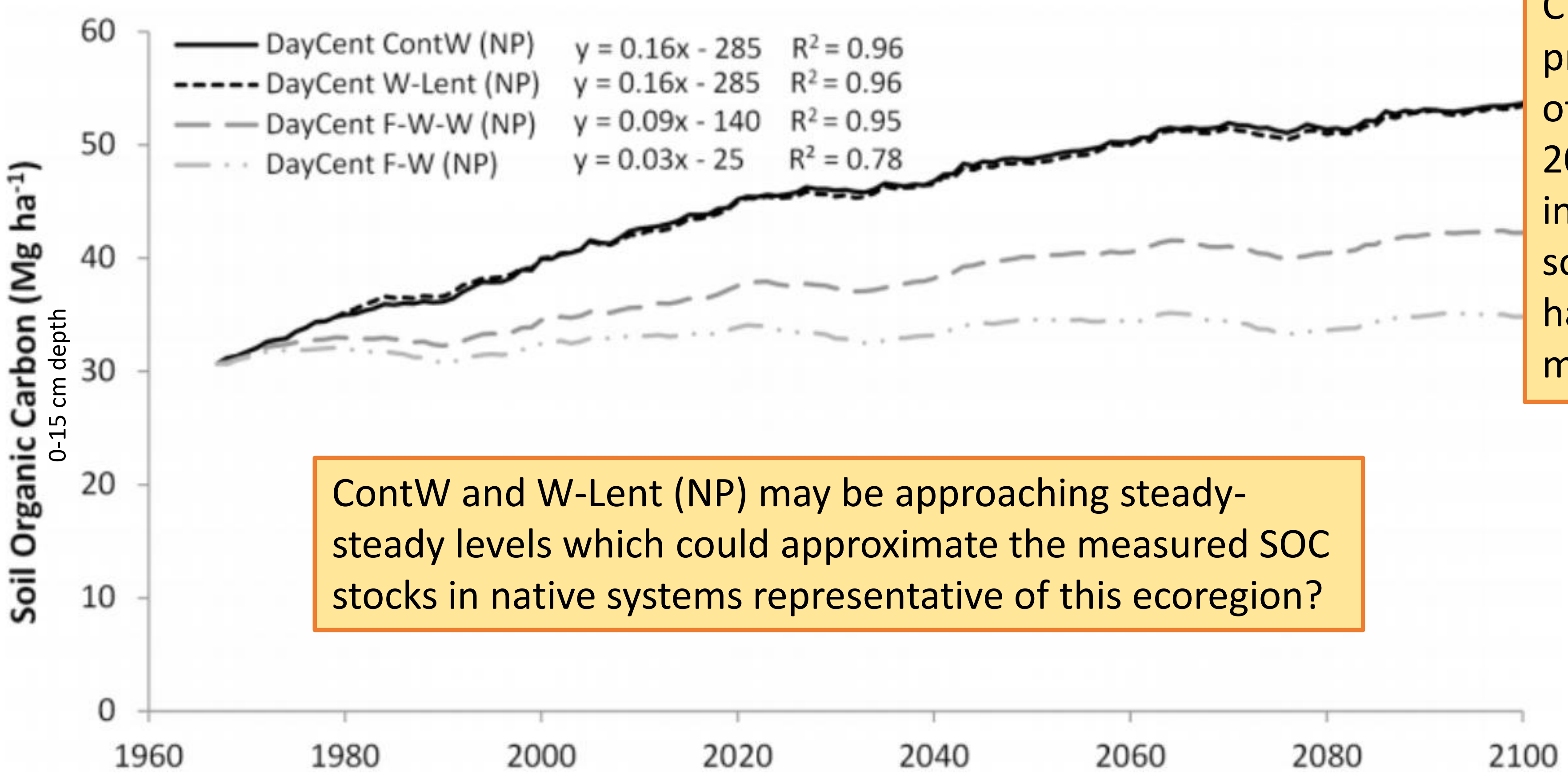
Reduction in Fallow increased SOC

Highest gains in SOC in well fertilized (NP) and continuously cropped rotations and that included rye or pulse crops



Congreves, K.A., Grant, B.B., Campbell, C.A., Smith, W.N., VandenBygaart, A.J, Kröbel, R., Lemke, R.L. & Desjardins, R.L. (2015). Measuring and modelling the long-term impact of crop management on soil C sequestration in the semiarid Canadian prairies. *Agronomy Journal*. 107: 1141-1154.

Swift Current Old Rotation Trial



For systems with high C input, DayCent projected SOC gains of 12 Mg C ha^{-1} from 2009 to 2100, indicating that the soil at Swift Current had not reached maximum C capacity.

Congreves, K.A., Grant, B.B., Campbell, C.A., Smith, W.N., VandenBygaart, A.J, Kröbel, R., Lemke, R.L. & Desjardins, R.L. (2015). Measuring and modelling the long-term impact of crop management on soil C sequestration in the semiarid Canadian prairies. *Agronomy Journal*. 107: 1141-1154.

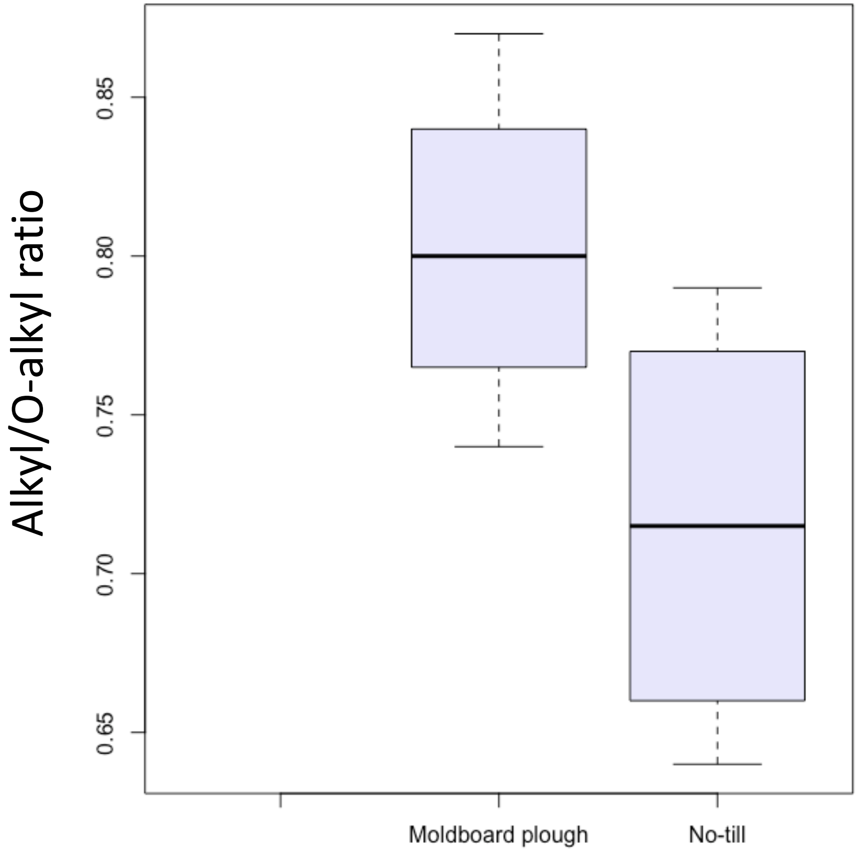
Key messages from other long-term sites

- Importance of AAFC long-term research trials
- More difficult to increase SOM in sandy soils than clays
  - Clays may protect SOM from mineralization
- Decreasing frequency of fallow (eliminating) key to increasing SOM
- Continuous C inputs (from roots and aboveground residues) key to increasing SOM
- Proper fertilization of growing crop key to improving SOM
- Including perennial crops in rotations appears to positively impact soil quality.

Nuclear Magnetic Resonance

Progressive SOM degradation typically results in a decline in O-alkyl C (cellulose, protein region of the NMR spectra)

Microbes prefer these substrates, so O-alkyl region may decline faster than other alkyl or aromatic compounds



Ploughing increased SOM degradation in general

Congreves, K.A. et al. *Preliminary research based on Dr. Bill Deen's longterm (30-yr) trial at Elora, Ontario*


But, reduced tillage is challenging to implement in intensive vegetable cropping systems…
What alternative methods might be effective in maintaining or improving soil health in these systems?

High Margin Crops!
Vegetables are more valuable, net $ CAD per acre

Tend to have really high fertilizer application (100-300 kg N ha^{-1})

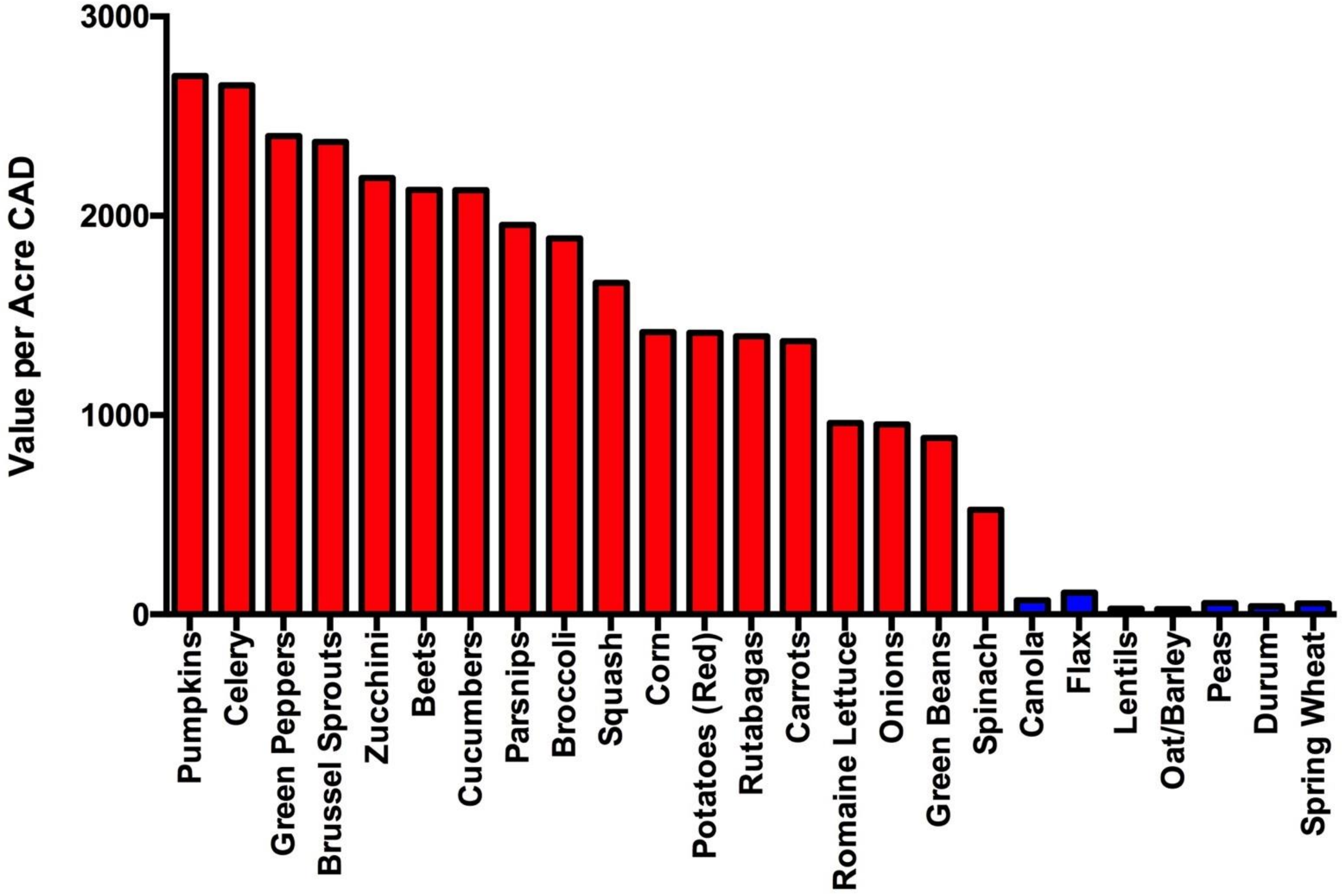


Figure credit: Dr. Sean Prager, data from most recent Stats Canada Data, Seracon Report, and Producer Organizations

Nutrient reservoir – research in progress

Fertility trials must take soil nutrient reservoirs into consideration

Photo Credit: T. Goff

- Irrigated Norland Red Table Potato
- Plot 9 m by 4m
- 30 cm spacing within row, 1 m spacing b/w row
- Fertilizer (urea and MAP) broadcast; incorporated

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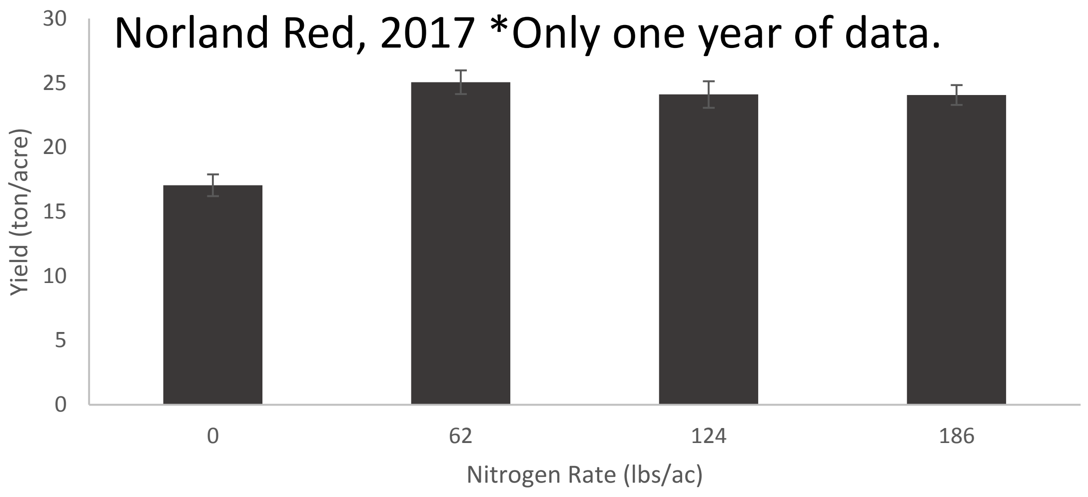
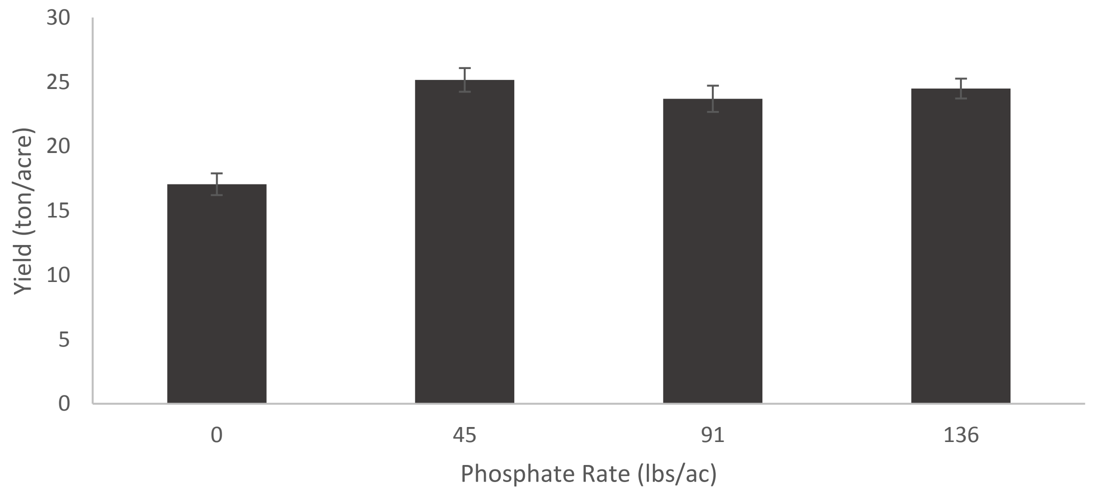
Norland Red, 2017 *Only one year of data.



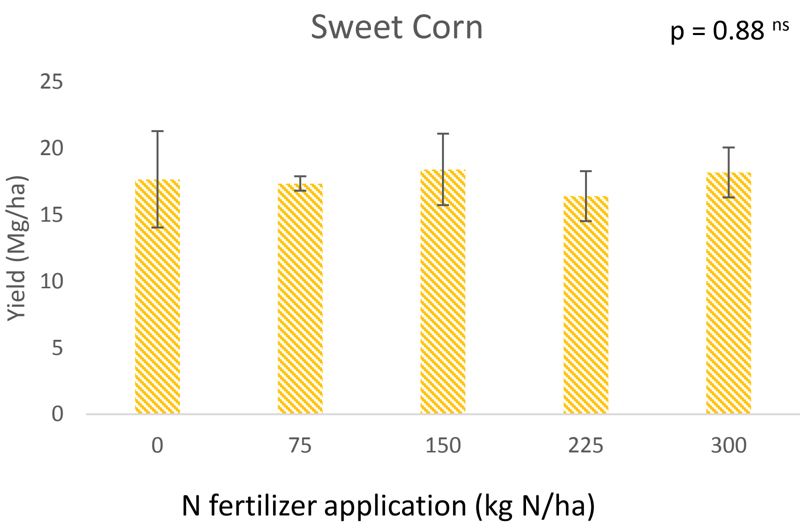


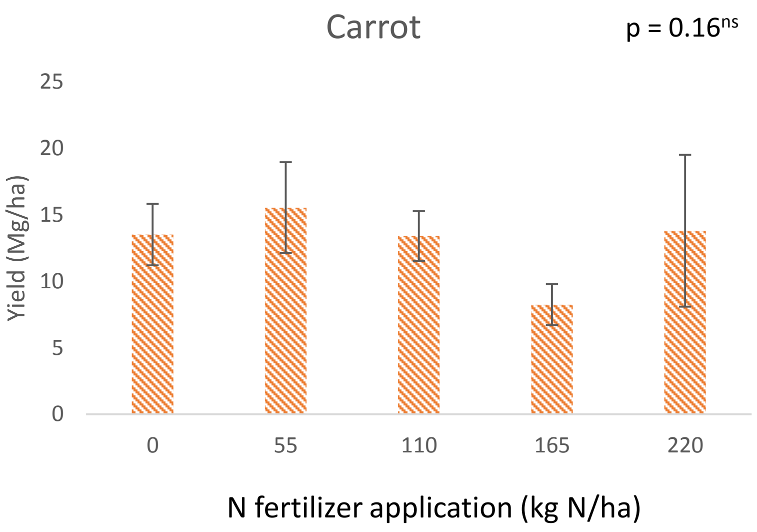
Ross, M., and Congreves, K.A. *Preliminary research*

Veg Research Team (Taryn Goff, Michelle Ross, & Jaime Taylor) harvesting potato (Photo Credit: K. Congreves)

Capacity of soil to function?
Is 'soil health' more important for crop production than fertilizer inputs?

*K. Congreves Preliminary data 2017 *Only one year of data.*

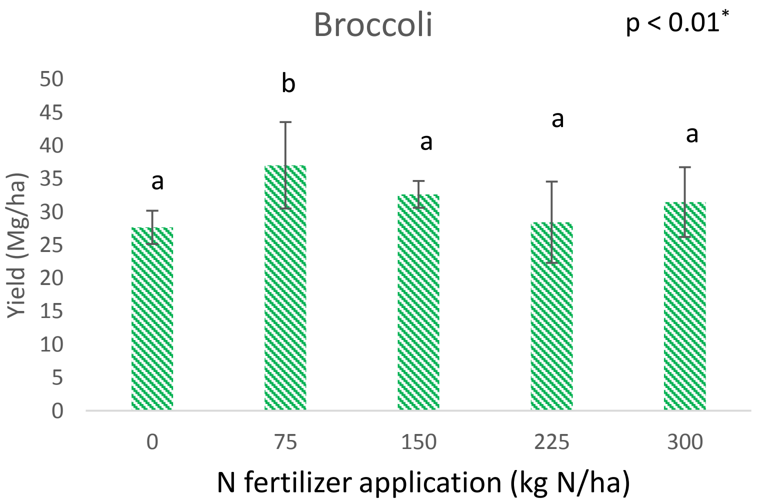




Carrot crop almost ready for harvest (photo credit: T. Goff).

Research technician Jamie Taylor in the sweet corn crop (photo credit: T. Goff).

Horticulture student Taryn Goff harvesting full broccoli plants for analysis (photo credit: K. Congreves)



Capacity of soil to function?
Is 'soil health' more important for crop production than fertilizer inputs?

Strengths and Limitations of Nitrogen Rate Recommendations for Corn and Opportunities for Improvement

Thomas F. Morris,* T. Scott Murrell, Douglas B. Beegle, James J. Camberato, Richard B. Ferguson, John Grove, Quirine Ketterings, Peter M. Kyveryga, Carrie A.M. Laboski, Joshua M. McGrath, John J. Meisinger, Jeff Melkonian, Bianca N. Moebius-Clune, Emerson D. Nafziger, Deanna Osmond, John E. Sawyer, Peter C. Scharf, Walter Smith, John T. Spargo, Harold M. van Es, and Haishun Yang

ABSTRACT

Nitrogen fixation by the Haber–Bosch process has more than doubled the amount of fixed N on Earth, significantly influencing the global N cycle. Much of this fixed N is made into N fertilizer that is used to produce nearly half of the world's food. Too much of the N fertilizer pollutes air and water when it is lost from agroecosystems through volatilization, denitrification, leaching, and runoff. Most of the N fertilizer used in the United States is applied to corn (*Zea mays* L.), and the profitability and environmental footprint of corn production is directly tied to N fertilizer applications. Accurately predicting the amount of N needed by corn, however, has proven to be challenging because of the effects of rainfall, temperature, and interactions with soil properties on the N cycle. For this reason, improving N recommendations is critical for profitable corn production and for reducing N losses to the environment. The objectives of this paper were to review current methods for estimating N needs of corn by: (i) reviewing fundamental background information about how N recommendations are created; (ii) evaluating the performance, strengths, and limitations of systems and tools used for making N fertilizer recommendations; (iii) discussing how adaptive management principles and methods can improve recommendations; and (iv) providing a framework for improving N fertilizer rate recommendations.

Core Ideas

- Nitrogen recommendations for individual corn fields are less accurate than desired.
- Nitrogen recommendations need improvement for economic and environmental reasons.
- A review of fundamental concepts will improve understanding about N recommendations.
- Examination of N recommendation systems, tests, and models will improve recommendations.

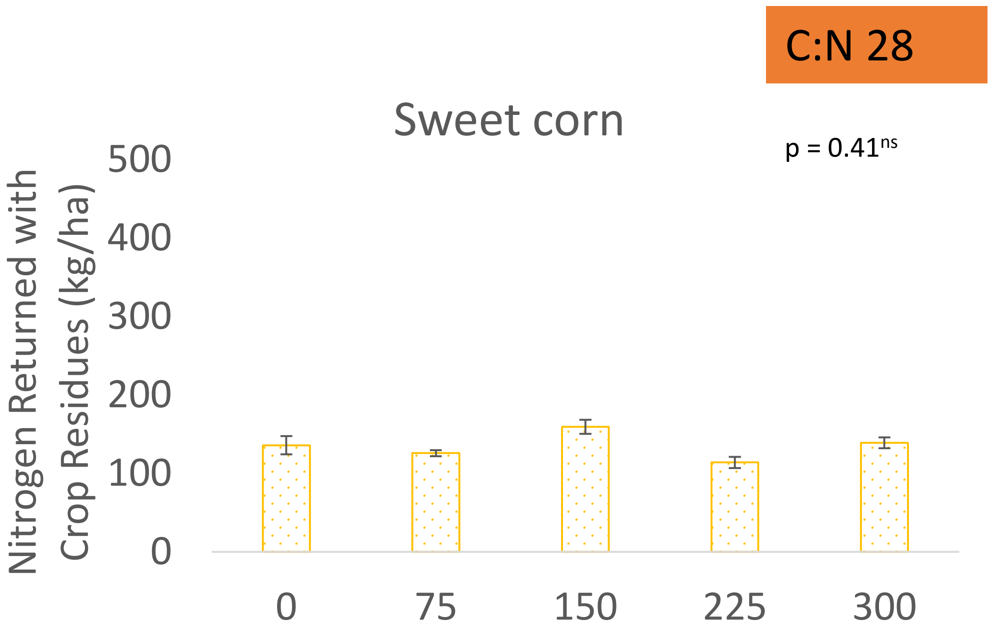
The goal of an N recommendation system is to accurately estimate the gap between the N provided by the soil and the N required by the plant. Accurately estimating this gap depends on the ability of the recommendation system to accurately estimate field or subfield specific economically optimal nitrogen rates (EONR). Current recommendation systems are not as accurate as needed to provide consistently reliable estimates of N needs across years at the field or subfield scale. Uncontrollable factors like temperature, rainfall timing, intensity and amount, and interactions of temperature and rainfall with factors such as N source, timing and placement, plant genetics, and soil characteristics combine to make N rate recommendations for an individual field or rates for subfields a process guided as much by science as by the best professional judgement of farmers and farm advisors.

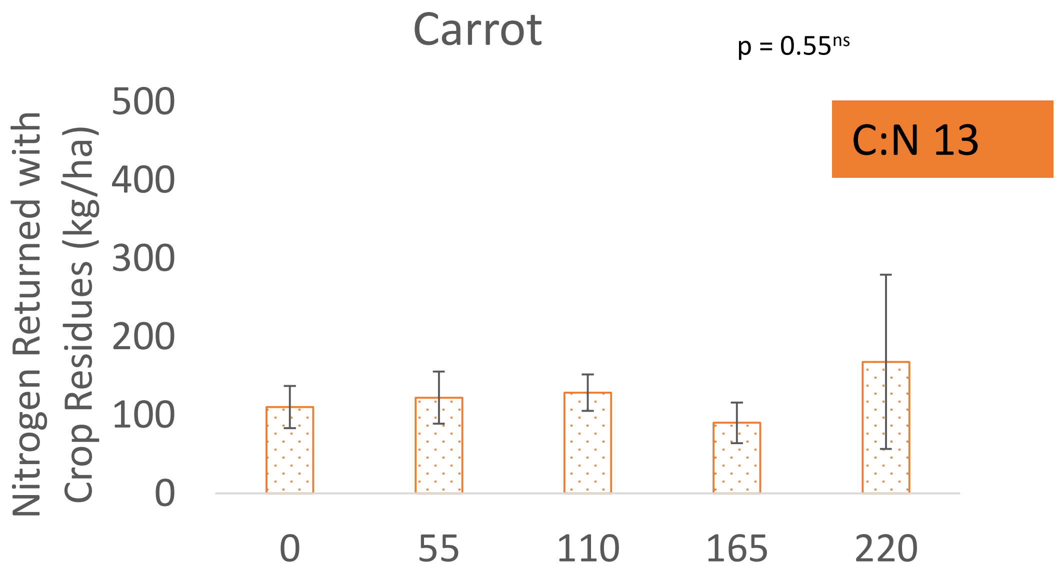
Substantial evidence has accumulated that EONRs can vary widely across fields, within fields and over years in the same field for a wide range of crops and geographies. Examples

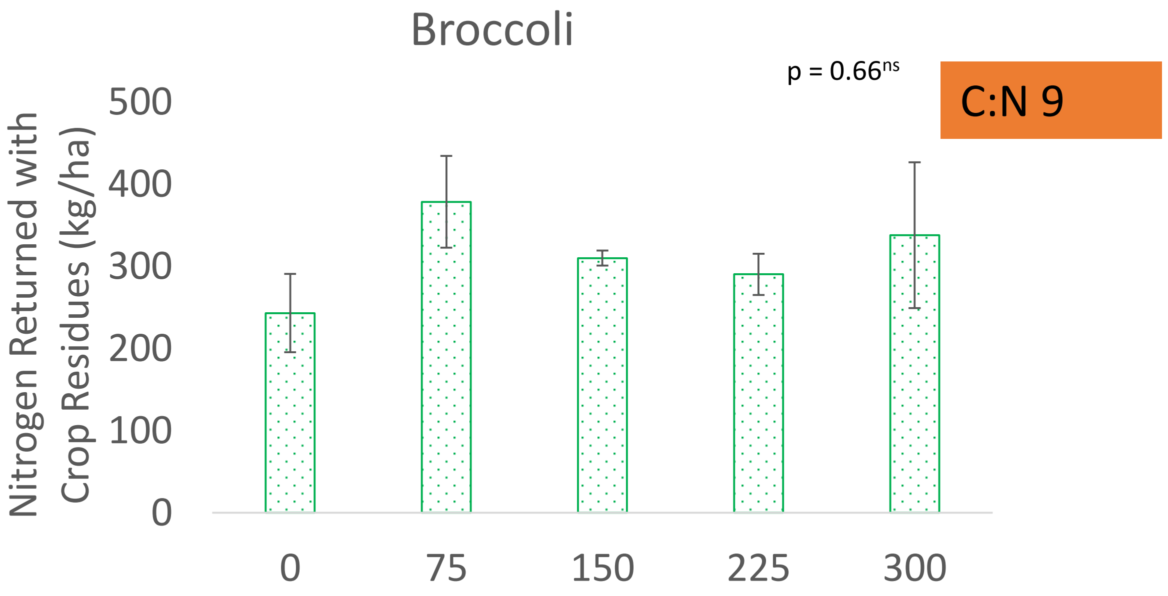
T.F. Morris, Dep. Plant Sci. and Landscape Architecture, Univ. of Connecticut, 1376 Storrs Rd, Storrs, CT 06269; T.S. Murrell, International Plant Nutrition Institute, P.O. Box 2539, West Lafayette, IN 47996; D.B. Beegle, Dep. of Plant Sci. Pennsylvania State Univ., 116 ASI Building, University Park, PA 16802; J.J. Camberato, Dep. of Agronomy, Purdue Univ., 915 W. State Street, West Lafayette, IN 47907; R.B. Ferguson and H. Yang, Dep. of Agronomy and Horticulture, Univ. of Nebraska, Lincoln, 377 K Plant Sci., Lincoln, NE 68583; J. Grove and J.M. McGrath, Dep. of Plant and Soil Sciences, Univ. of Kentucky, Ag Sci. North, Lexington, KY 40546; Q. Ketterings, Dep. of Animal Sci., Cornell Univ., Morrison Hall, Ithaca, NY 14853; P.M. Kyveryga, Iowa Soybean Association, 1225 SW Prairie Trail Parkway, Ankeny, IA 50023; C.A.M. Laboski, Dep. of Soil Sci., Univ. of Wisconsin, 1525 Observatory Dr., Madison, WI 53706; J.J. Meisinger, BARC-EAST, USDA-ARS, 10300 Baltimore Ave, Beltsville, MD 20705; J. Melkonian, B.N. Moebius-Clune, and H.M. van Es, Dep. of Crop and Soil Sciences, Cornell Univ., Bradfield Hall, Ithaca, NY 14853; E.D. Nafziger, Crop Sciences, Univ. of Illinois, 1102 South Goodwin Ave., Urbana, IL

https://dl.sciencesocieties.org/publications/aj/pdfs/110/1/1

*K. Congreves Preliminary data 2017 *Only one year of data.*







Regardless of crop type, large amounts of N returned were returned to the soil after harvest in the form of ‘readily mineralizable’ crop residues! 90-379 kg N ha^{-1}


Photo Credit: K. Congreves

- May translate in to high risks for potential N losses during the non-growing season. our results clearly demonstrate the importance of considering post-harvest N management.

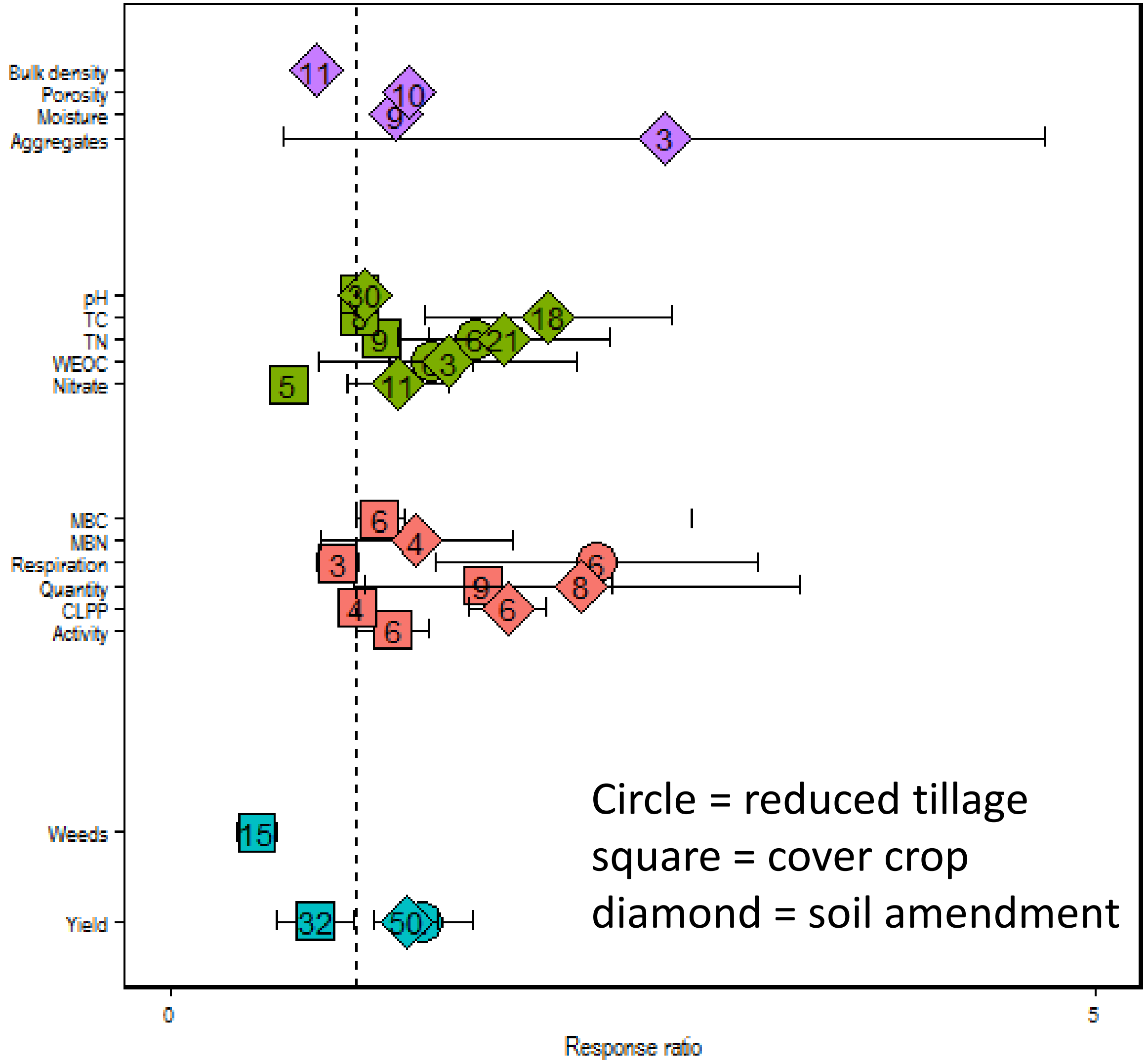
- Post-harvest N management might include strategies like i) **cover cropping** to reduce potential losses during the non-growing season, or ii) **taking into account soil-test N levels** in the following spring to avoid repeatedly over-applying N fertilizer in veg production.

Established fall rye cover crop where the broccoli crop was previously grown (photo credit J. Taylor)

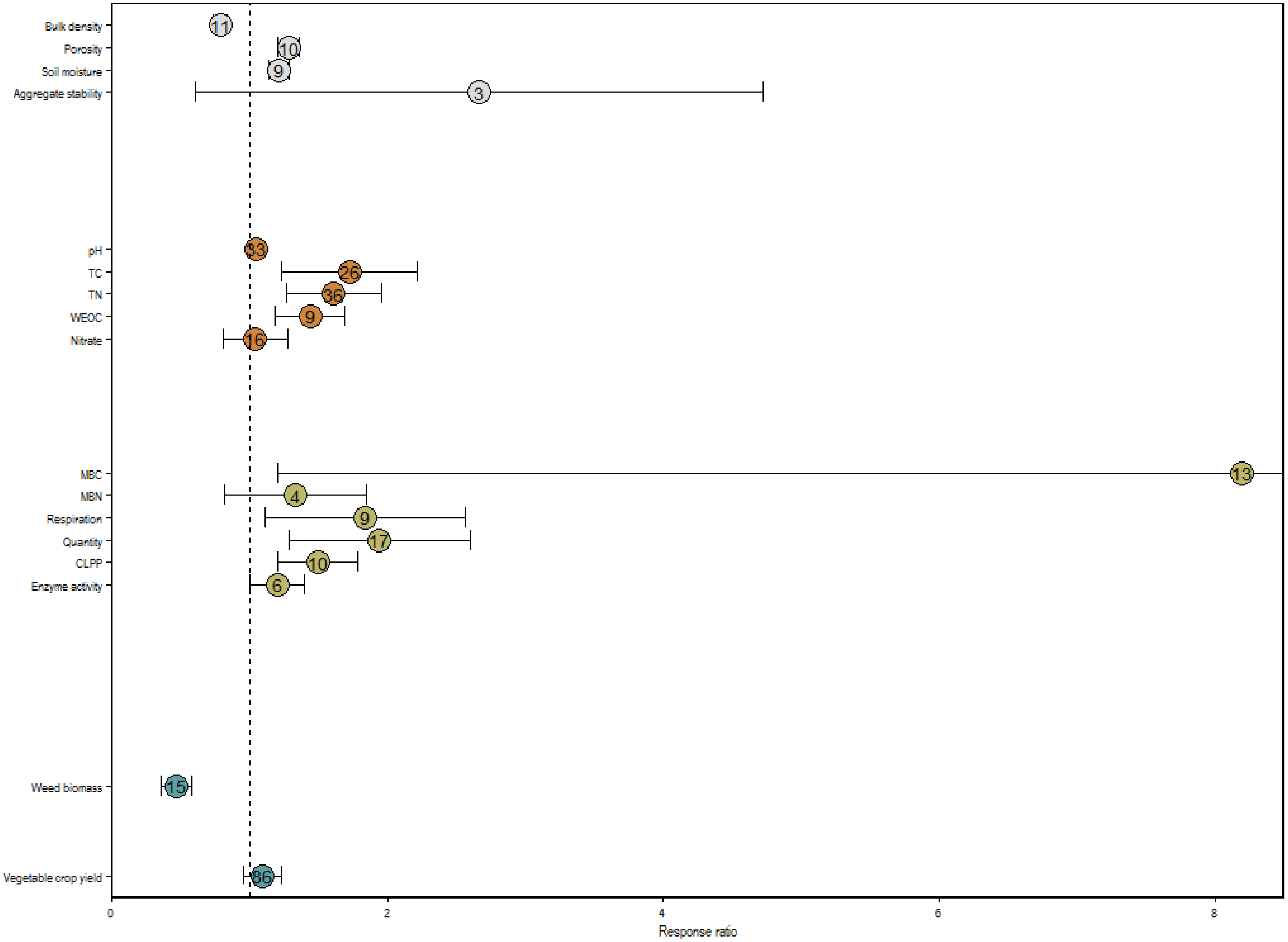
Fall rye cover crop beginning to germinate where the carrot crop was previously grown (photo credit J. Taylor)

Blending the ideologies of organic and conventional agriculture to improve soil health indices in intensive vegetable cropping systems?

- 64 papers
- North/South American & European systems
- Alternative practices in intensive veg production
  - Amendments
  - Cover crops
  - Reduced tillage



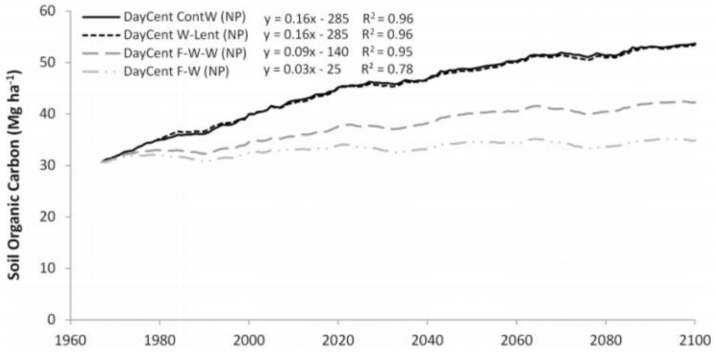
Drs. Charlotte Norris & K. Congreves Preliminary Data 2018

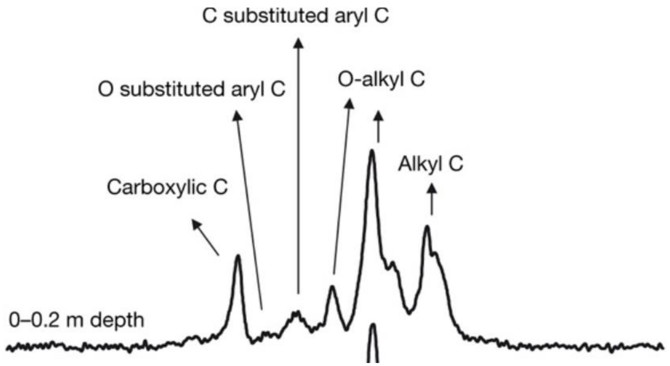


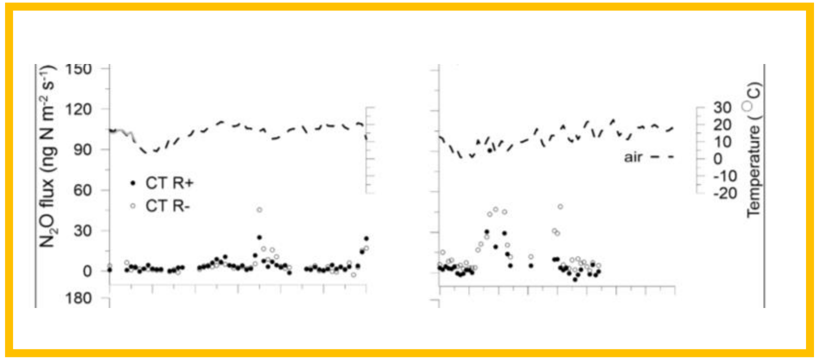
Drs. Charlotte Norris & K. Congreves Preliminary Data 2018

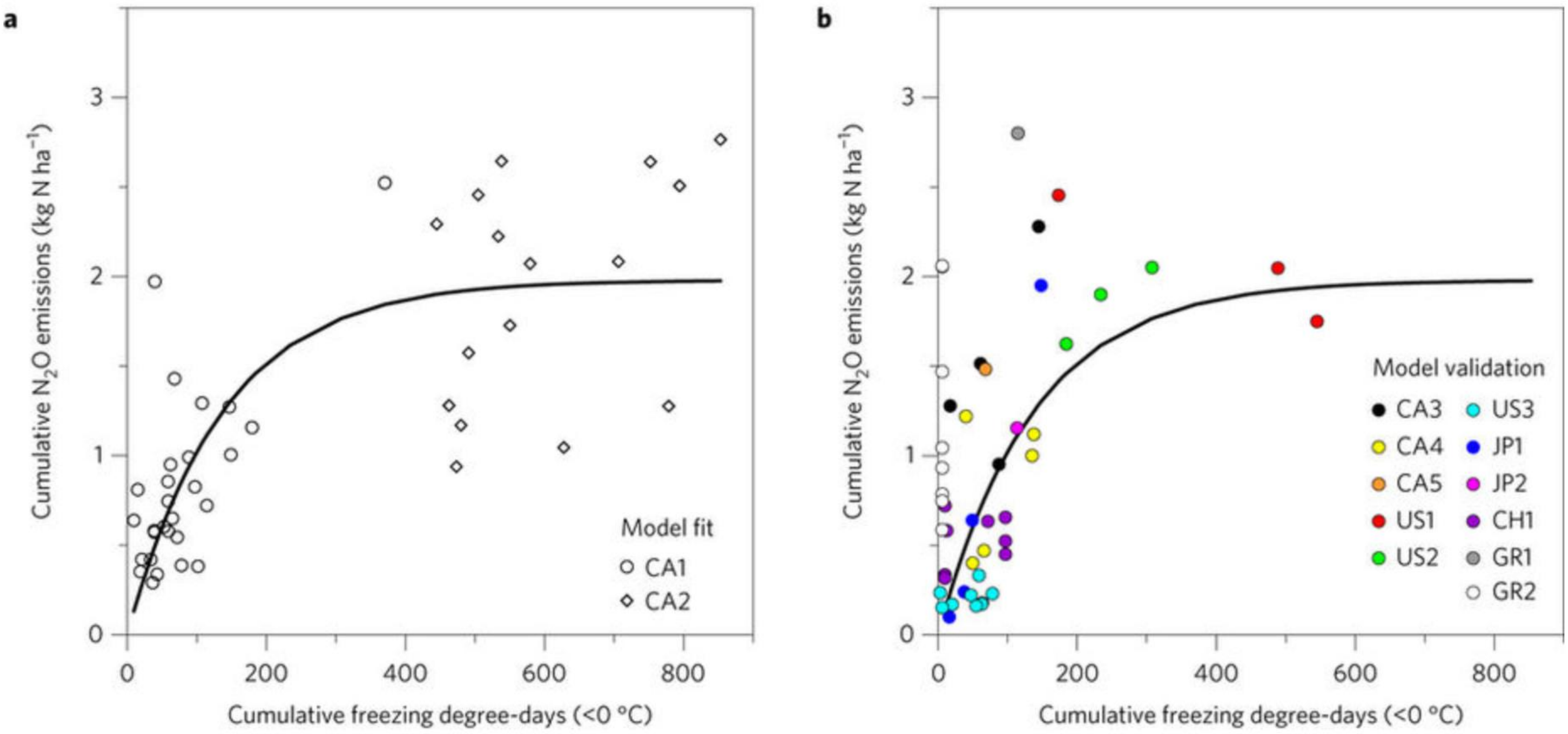
Soil health, organic matter, and functioning

Soil nutrient reservoir → Soil carbon storage → Soil nitrous oxide emissions









Wagner-Riddle, C., Congreves, K.A., Abalos, D., Berg, A.A., Brown, S.E., Ambadan, J.T., Gao, X. & Tenuta, M. (2017). Globally important nitrous oxide emissions from croplands induced by freeze-thaw cycles. *Nature Geoscience*. 10: 279-283.

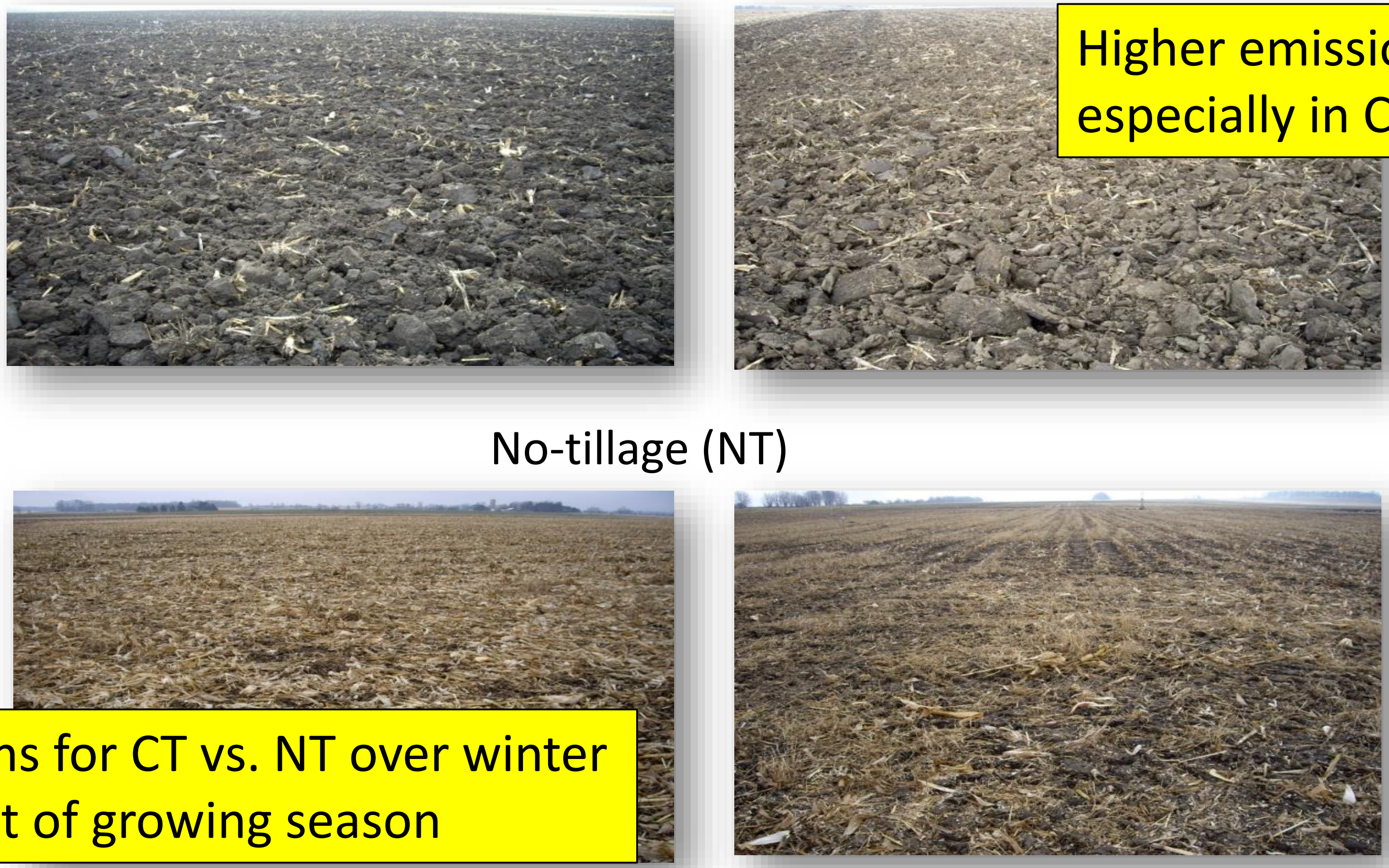
- Organic matter from crop residues may be an important factor in reducing N_2O emissions at winter/spring thaw – more complete denitrification? Helps to insulate soil against lower temperatures?

Conventional tillage (CT)

Residue returned (R+)

Residue removal (R-)

No-tillage (NT)



Higher emissions for R- vs. R+, especially in CT

Higher emissions for CT vs. NT over winter but not at onset of growing season

Congreves, K.A., Brown, S.E., Németh, D.D., Dunfield, K.E. & Wagner-Riddle, C. (2017). Differences in field-scale N_2O flux linked to crop residue removal under two tillage systems in cold climates. *Global Change Biology Bioenergy*. 9: 666-680.

University of Saskatchewan
College of Agriculture and Bioresources

Soil organic matter matters for soil health

Conservation management practices key for soil organic matter & soil functioning

kate.congreves@usask.ca

Twitter@KateCongreves

Website: http://researchers.usask.ca/kate-congreves/

University of Saskatchewan, College of Agriculture and Bioresources, Dept of Plant Sciences

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UNIVERSITY OF SASKATCHEWAN
College of Agriculture and Bioresources
DEPARTMENT OF PLANT SCIENCES
AGBIO.USASK.CA

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